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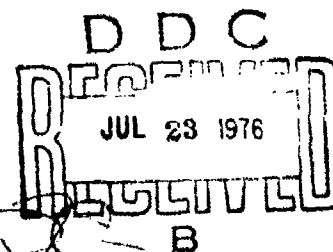
COMPARISONS BETWEEN MEASURED AND PREDICTED SURGE,

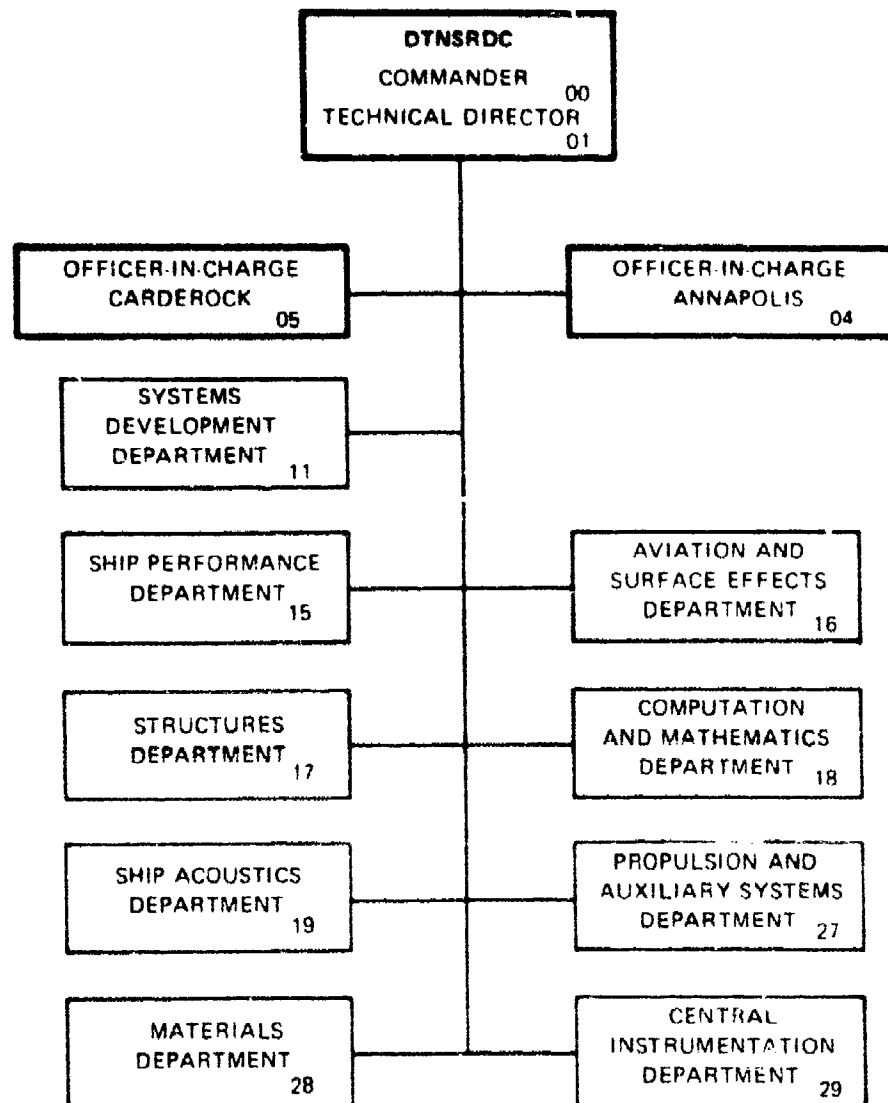SWAY, AND YAW FOR LCU 1610 AND FF 1006

by

A. E. Baitis

and

T. R. Applebee

D D C

JUL 23 1976

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SHIP PERFORMANCE DEPARTMENT

June 1976   SPD-694-01

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Comparisons between experimental and predicted surge, sway, and yaw motions for an LCU 1610 and the FF 1006 operating at various headings to regular waves are presented. In addition, comparable predictions are given for an ocean construction barge.

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NOTATION

CL	Longitudinal centerline
F_n	Froude number
GM	Transverse metacentric height
K	Wave number $(2\pi/\lambda)$
KG	Height of center of gravity above baseline
L	Ship length
WL	Waterline
x	Surge
y	Sway
ζ_a	Wave amplitude (single amplitude)
θ	Pitch
λ	Wavelength
ϕ	Roll
ψ	Yaw

ABSTRACT

Comparisons between experimental and predicted surge, sway, and yaw
motions for an LCU 1610 and the FF 1006 operating at various headings to regular
waves are presented. In addition, comparable predictions are given for an
ocean construction barge.

ADMINISTRATIVE INFORMATION

INTRODUCTION

DTNSRDC was requested by NAVFACENGCOM to provide comparative information,
developed by theoretical methods and experimental methods, on the wave-induced
motions of ships floating freely with no way on. Specifically, data for three
ships were requested, i.e., a destroyer, a small 509 metric ton derrick barge,
and a large 2387 metric ton ocean construction barge.

It was determined that the comparisons should be made on the basis of
transfer functions as determined by both theoretical and experimental methods.
Transfer functions are the responses of the ship, in the various degrees of
freedom, per unit height or slope of regular, sinusoidal waves. The comparative
information of primary interest, particularly with regard to the barges,
concerned responses in the surge, sway, and yaw degrees of freedom. Although
existing theory, implemented by computer programs, was available for obtaining
the theoretical responses, and experimental data for the FF 1006 was available
from earlier model experiments, no experimental information was available for
the barges. Therefore it was decided to conduct a rather limited model experi-
ment in the DTNSRDC Maneuvering and Seakeeping Basin to develop experimental
surge, sway, and yaw transfer functions for the barges.

Since models of the barges were not available, and the cost of constructing them was beyond the funding scope, it was decided to perform simplified surge-sway-yaw experiments for the two barges with available models of roughly similar dimensions. Thus, comparison between results of experiment and theory for the actual model could then be employed to estimate the variability between experiment and theory for the barges of specific interest. A model of the 349 metric ton LCU 1610 was employed as the approximation of the 509 metric ton derrick barge, and a model of a Maritime Administration barge scaled to 2387 metric tons was used to represent the 2387 metric ton ocean construction barge. Unfortunately, during the experiments with the LCU model, it became evident that the experimental technique and equipment made it impossible to conduct the simple, inexpensive model experiments that were anticipated. These difficulties with the experimental procedure, in fact, precluded any experiments with the larger barge.

The experiments to determine surge, sway, and yaw transfer functions for a small frigate, the FF 1006, were conducted with the model propelled at a full-scale speed of nine knots at various headings in regular waves.

This report describes, and comments on, the experimental procedures and techniques, with particular attention given to the problems arising from deficiencies in the technique; presents results in the form of comparisons of transfer functions as determined theoretically and experimentally; presents an analysis of the results; and offers concluding comments concerning the validity of the investigation. It should be noted that in the case of the ocean barge only the theoretical results are presented inasmuch as the companion experiments were not conducted.

EXPERIMENTS

The experiments were conducted in the seakeeping basin at the Maneuvering and Seakeeping Facility at DTNSRDC. This basin is 360 feet (109.7 metres) long and 240 feet (73.2 metres) wide, with a measured depth of 19.5 feet (5.9 metres).

Both the LCU and the FF 1006 experiments were performed with essentially free running models that were connected to the test carriage by an umbilical cord

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containing the power and data transducer cables. In addition, two restraining ropes (see Figure 1) were used to position the model below the carriage at the appropriate heading to the waves, i.e., 180 degrees designates head seas, 90 degrees designate beam seas, and 45 degrees designate quartering seas. Experiments at these three headings were conducted to maximize the responses in surge (180 degrees), sway (90 degrees), and yaw (45 degrees).

Waves were generated by a bank of pneumatic wavemakers while beaches on the opposing side of the basin absorbed wave energy and thus reduced wave reflections sufficiently to allow the generation of nearly perfect sinusoidal waves. Experiments were conducted over a range of wavelengths sufficient to define the ship motion transfer functions, i.e., wavelength to ship length ratios from 0.4 to 4.0. Wave heights were generally maintained at heights corresponding to wavelength to height ratios of about 80.

MEASUREMENT AND ANALYSIS SETUP AND PROCEDURE

Unless otherwise noted, the instrumentation setup and procedure were identical for both the LCU and the FF 1006 experiments. Gyroscopes were used to obtain angular displacements (roll, pitch, and yaw measurements) and ultrasonic transducers were used to obtain linear displacements (sway and surge measurements). Surge and heave were also measured with accelerometers to assist in defining stable ship response conditions for data analysis purposes. Figure 1 presents a general sketch of the instrumentation arrangement.

The roll and pitch gyroscope as well as the yaw gyroscope were mounted on the centerline, near the longitudinal center of buoyancy. The accelerometers were similarly located.

LCU sway was measured with an ultrasonic transducer mounted on the model at midships and at deck level. This transducer sent its signal to a target or echo board mounted to the carriage near the water surface. The target board was mounted 2.5 feet (.762 metres) away from and parallel to the centerline of the model in its at-rest position. The reflected signal was recovered by a receiver mounted on the model as part of the transmitter. This basic technique of linear measurement was used for both surge and sway during the FF 1006 model experiments.

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LCU surge was measured with the same basic ultrasonic transducer, although in this case, the transmitters and receiver were separated to improve the range of the device. The transmitters were mounted on a board attached to the carriage near the water surface, directly ahead of the at-rest position of the model, and the receiver was mounted on the centerline at the bow deck edge. It should be noted that the surge transducer was sensitive, both to large vertical and large fore and aft displacements which tended to shift the receiver out of the path of the relatively narrow (16-degree cone width) transmitting beam. In order to overcome these transducer limitations, an array of three co-planar transmitters was mounted 3.5 feet (1.067 metres) ahead of the model in its at-rest position.

All measurements were recorded on strip charts and magnetic tape. In addition, response amplitude to wave amplitude ratios were obtained during the LCU experiments using an Interdata minicomputer mounted on the test carriage. During the FF 1006 experiments,[1] which were performed several years earlier, the strip charts were analyzed manually to provide the ship response data.

OBSERVATIONS ON EXPERIMENTAL TECHNIQUE

During the FF 1006 experiments, zero speed motion measurements were not made due to the difficulty in making such measurements. Since the zero speed ship responses were not of major interest in the FF 1006 experiments, attempts to refine the experimental technique to collect such data were not made. In this context it should be noted that the course of the FF 1006 model was controlled by means of an automatic steering system that moved the rudder in proportion to yaw angle and yaw rate. At zero speed, of course, the rudder was unable to maintain the desired heading relative to the waves.

The LCU experiments were performed entirely at zero speed so that these low speed experimental difficulties could not be entirely avoided.

During the data collection segment of the experiment, the model was unrestrained. The umbilical power and instrumentation cables, and the restraining

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[1]Baitis, A.E. and R. Wermter, "A Summary of Oblique Sea Experiments Conducted at The Naval Ship Research and Development Center," Appendix 8 of the Seakeeping Committee Report, 135th International Towing Tank Conference, 1972.

or positioning ropes did not provide sufficient force to prevent either yawing, surging or general drifting due to wave action. This technique of zero speed ship motion measurements will produce realistic ship responses uncorrupted by various realistic or unrealistic restraining forces. Unfortunately, it is quite difficult to collect sufficient stable data before surge, sway or yaw has departed substantially from the mean positions.

The first motion of major concern investigated was surge in head seas.* Because of inherent problems in model control at this heading at zero speed, this was the most difficult portion of the experiment. As the waves encountered the unrestrained model, extreme and rapid aftward drifting resulted. By restraining the model for the first few waves and then releasing it at precisely the right moment, this violent drifting could be impeded until data was collected. However, although this method successfully prevented gross variations in model attitude, it did not eliminate the transient changes in heading associated with the free-drifting model. Even in beam and quartering waves, where extreme drifting was not as much of a problem, definite shifts from initial heading were observed. In fact, the signals from the ultrasonic transducers were often lost, pointing up the magnitude of directional change which occurred. Since a change in heading will produce a change in the ship response per unit wave height at constant wave height, some inaccuracies or scatter in the measured response values are inherent in this type of experiment.

It was concluded from these experiments that realistic, free model experiments at zero speed cannot be effectively performed. Either small, though steady, and properly balanced restraining forces must be employed in such experiments, or the experiments must be performed at forward speed. It is recommended that equipment to provide restraining forces be developed and employed before another such zero speed experiment with very limited funding be initiated.

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*The term "seas" as used in this report refers to regular waves.

THEORETICAL PREDICTIONS

The nondimensional transfer functions were computed on a CDC 6700 digital computer using the NSRDC Ship-Motion and Sea-Load Computer Program.[2] This program predicts the six degree of freedom ship motions for a ship advancing at constant speed with an arbitrary heading in regular waves. The hydrostatic quantities for the vessels, as computed by the program, are presented in Tables 1, 2, and 3. The computer fits of the underwater portions of the ship hulls are similarly presented in Figures 2, 3, and 4 for the LCU, the ocean construction barge, and the FF 1006, respectively. A sketch of the construction barge, the ex-YFNB-33 hull, is shown in Figure 5.

RESULTS

Results are presented in two basic figures which present for various headings the transfer functions as a function of λ/L (wavelength/ship length). Sway and surge are nondimensionalized by wave amplitude, ζ_a, and pitch, roll, and yaw by wave slope, $(2\pi\zeta_a)/\lambda$. The pitch and roll motions are presented as comparative responses.

Figure 6 presents the experimental LCU transfer function values and the corresponding predicted functions at headings that tended to maximize surge (180 degrees), sway (90 degrees), and yaw (45 degrees). The maximum yaw transfer functions figure, Figure 6a, also presents the associated surge and sway data. Similarly, the maximum sway transfer function figure, i.e., Figure 6b, presents the associated roll, surge, and yaw; and the maximum surge transfer function is presented in Figure 6c along with the associated pitch, sway, and yaw data.

It should be noted that the predicted transfer functions for the ocean barge are also shown for comparative purposes in Figure 6.

The experimental data and corresponding predictions for the FF 1006 have also been assembled into a single figure, Figure 7. This figure presents

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[2]Meyers, W.G., D.J. Sheridan and N. Salvesen, "Manual – NSRDC Ship-Motion and Sea-Load Computer Program," NSRDC Report 3376, Feb 1975.

measured and predicted transfer functions for surge, sway, and yaw at 9 knots
in bow seas (135 degrees), beam seas (90 degrees), quartering seas (45 degrees),
and following seas (0 degrees).

ANALYSIS

Before proceeding with a comparison between the predicted and measured
data, several general comments regarding trends in surge, sway, and yaw as a
function of ship heading are made. These trends are based on regular wave
predictions. First, sway, yaw, and roll are zero in head and following seas.
Second, surge tends to be large in both head and following seas and, in the
case of the LCU, at zero speed* surge is essentially of equal magnitudes at
both headings. Third, it is also noted that the predicted sway attains a
maximum value in beam waves where both surge and yaw are zero and pitch is also
essentially equal to zero. Finally, all of the predicted transfer functions
are non-zero in bow and quartering seas.

In general, it may be noted that the differences between the predicted
responses for the rather small 347 metric ton LCU and the 2387 metric ton ocean
construction barge are less than the differences between measured and predicted
transfer functions for the LCU.

The large number of experimental data points required to define the
transfer functions, and the associated scatter in the measured data illustrate
clearly the difficulties in model surge, sway, and yaw control during the ex-
periments. The data points for head sea sway and yaw, and beam sea surge and
yaw, are non-zero and thus represent essentially direct measures of the experi-
mental causes for errors inherent in the corresponding surge and sway results.

Generally, the experimental head sea surge and pitch agree well with
predictions, although the measured surge is significantly lower than the pre-
dictions for wavelengths ranging from about 1.2 to 1.8 times the ship length.

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*Based on calculations of transfer functions at speeds other than zero,
following sea surge begins to exceed head sea surge by appreciable margins
as speed increases.

Measured sway in beam and quartering seas is substantially lower than the predictions. In fact, the measured beam sea sway is much lower at the shorter wavelengths than indicated by the predictions. The agreement between measured and predicted roll in beam waves is considered to be excellent.

Measured quartering sea yaw, unlike any of the other measured ship responses at this and other headings, is clearly underpredicted by the existing computer programs. It is not entirely clear, however, whether these discrepancies between theory and experiment are due to inadequacies in the theory or in the experimental procedure.

In general, the predicted surge and sway appear to be conservative, i.e., larger than measurements, whereas the yaw data suggests that the existing program or theory may actually underpredict yaw.

A comparison between predictions and measurements made for the FF 1006 in Figure 7 similarly suggests that yaw may be seriously underpredicted at 9 knots in quartering waves. The agreement between theory and measurement is considered to be satisfactory for surge, though unsatisfactory for sway and yaw. Particular attention is called to the glaring disagreement in beam seas sway in the λ/L range from 0.5 to 1.2. It should be pointed out that the rectangular symbols represent results from sway beam sea experiments at a speed of 27 knots. The 27-knot sway data agrees well with the 9 knot data, suggesting that sway in beam seas is speed independent.

A comparison of the measured beam sea sway at zero knots for the LCU and the comparable sway at 9 knots for the FF 1006 suggest similarities in that both transfer functions exhibit a local minimum value at λ/L of about 1.2. In addition, the sharply peaked sway response at wavelengths shorter than λ/L = 1.2 and the general sway trend at λ/L > 1.2 are similar for both sets of results. The predicted sway for either the LCU or the FF 1006 does not follow the experimental data trends. These sway comparisons suggest deficiencies in the basic theory, rather than deficiencies in the experimental technique.

It is concluded on the basis of the above data that refined experiments are required in order to validate the predicted surge, sway, and yaw results.

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CONCLUDING REMARKS

Although the agreement between measurements and theory indicate substantial differences at various conditions for surge (i.e., λ/L between 1.2 and 2.0 head seas), for sway (in beam seas), and for yaw (in quartering seas), the source of the disagreements cannot be derived with certainty from the present results. Refined experimental procedures and refinements in the theory are required in order to improve the confidence with which the existing programs may be used in engineering calculations.
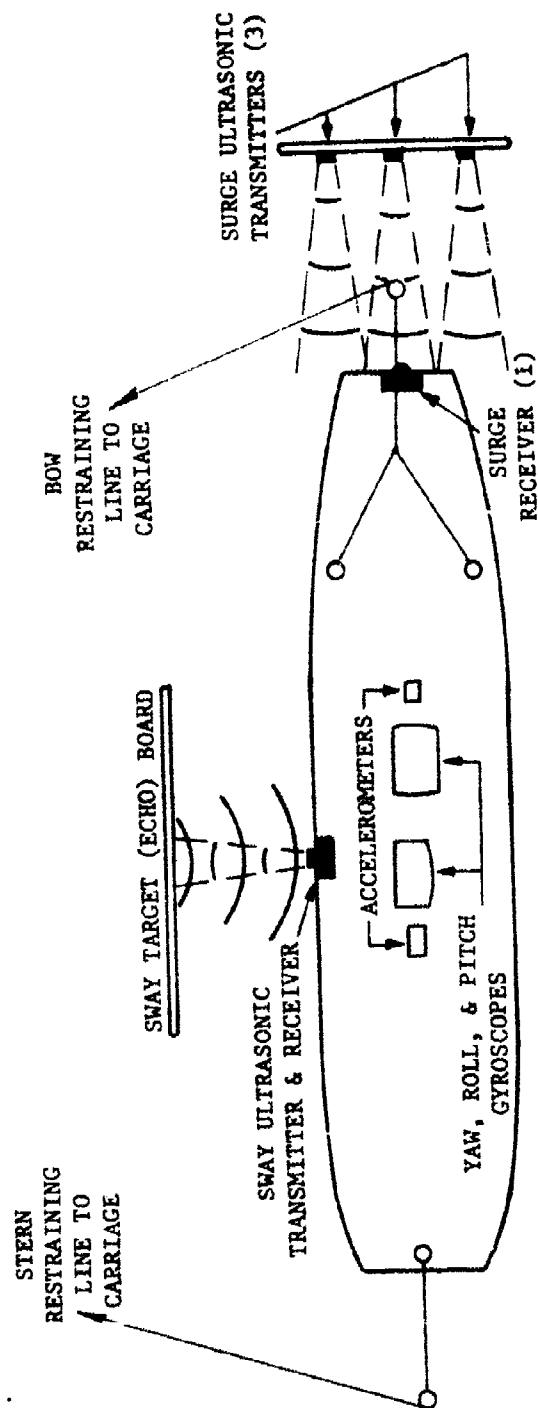
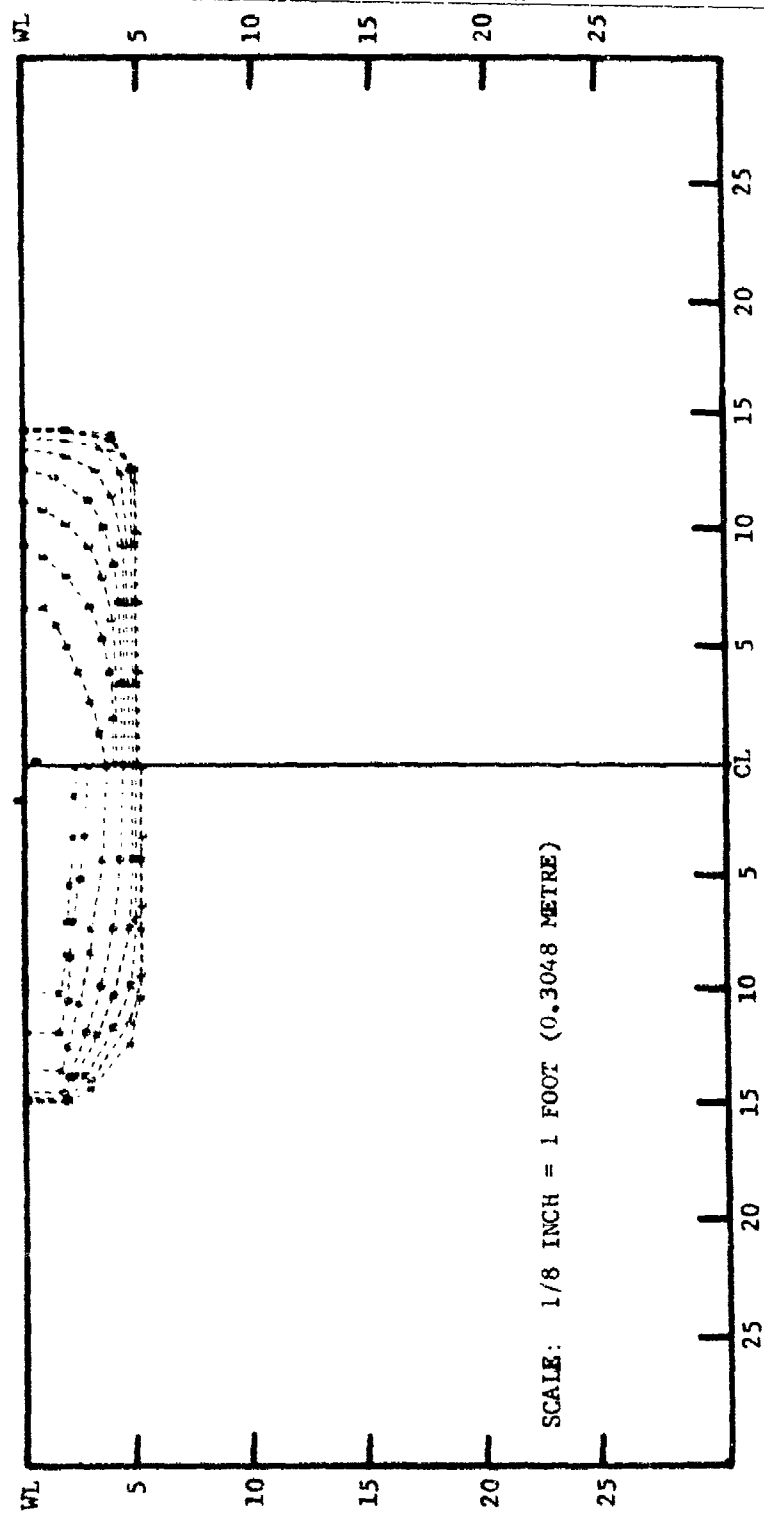Figure 1 – Sketch of Instrumentation Arrangement

SURGE ULTRASONIC TRANSMITTERS (3)

BOW RESTRAINING LINE TO CARRIAGE

SURGE RECEIVER (i)

SWAY TARGET (ECHO) BOARD

SWAY ULTRASONIC TRANSMITTER & RECEIVER

ACCELEROMETERS

YAW, ROLL, & PITCH GYROSCOPES

STERN RESTRAINING LINE TO CARRIAGE

Figure 2 — Computer-fit of LCU 1610 Body Plan

SCALE: 1/8 INCH = 1 FOOT (0.3048 METRE)

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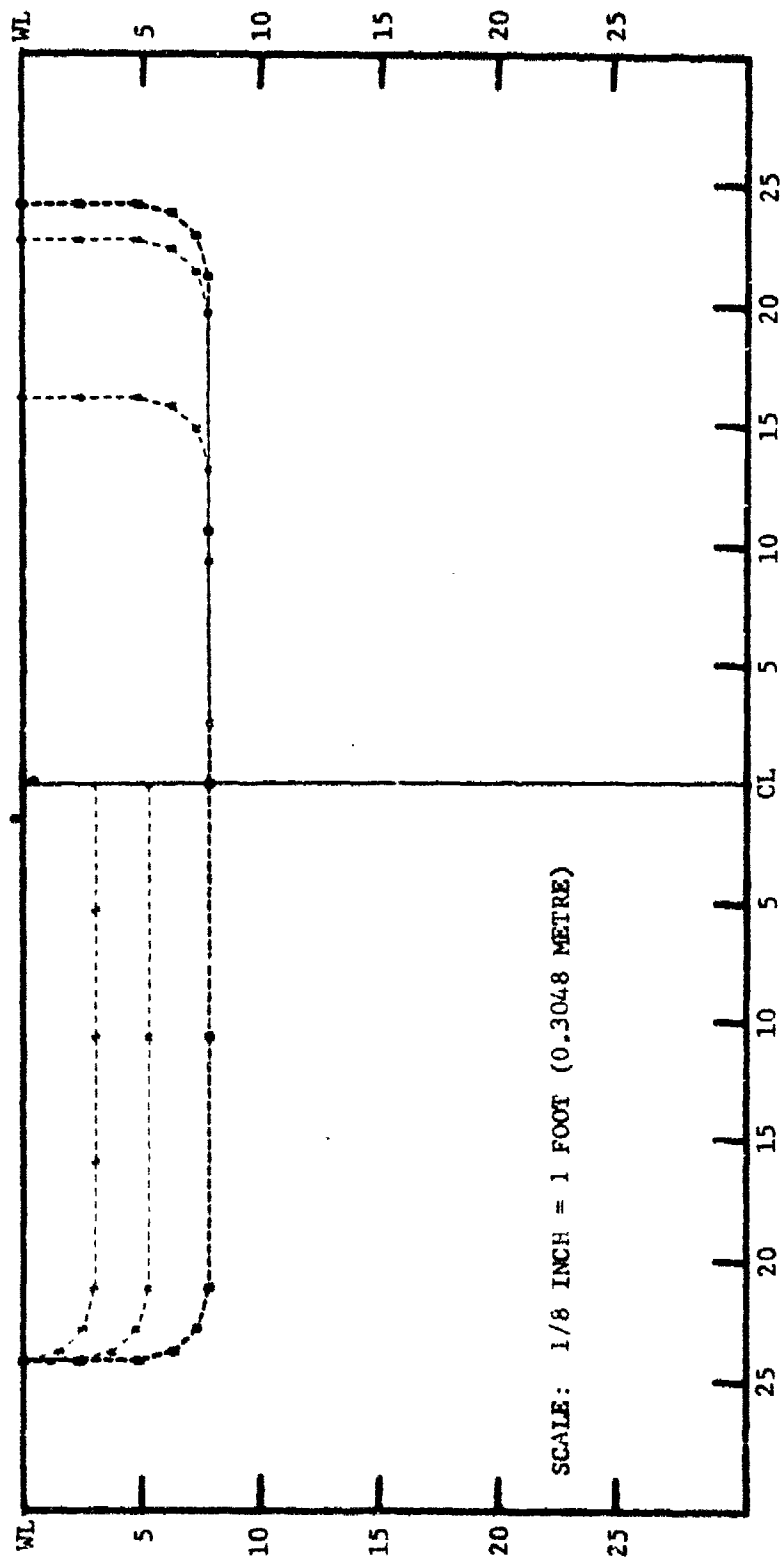
Figure 3 - Computer-fit of Ocean Construction Barge Body Plan

SCALE: 1/8 INCH = 1 FOOT (0.3048 METRE)

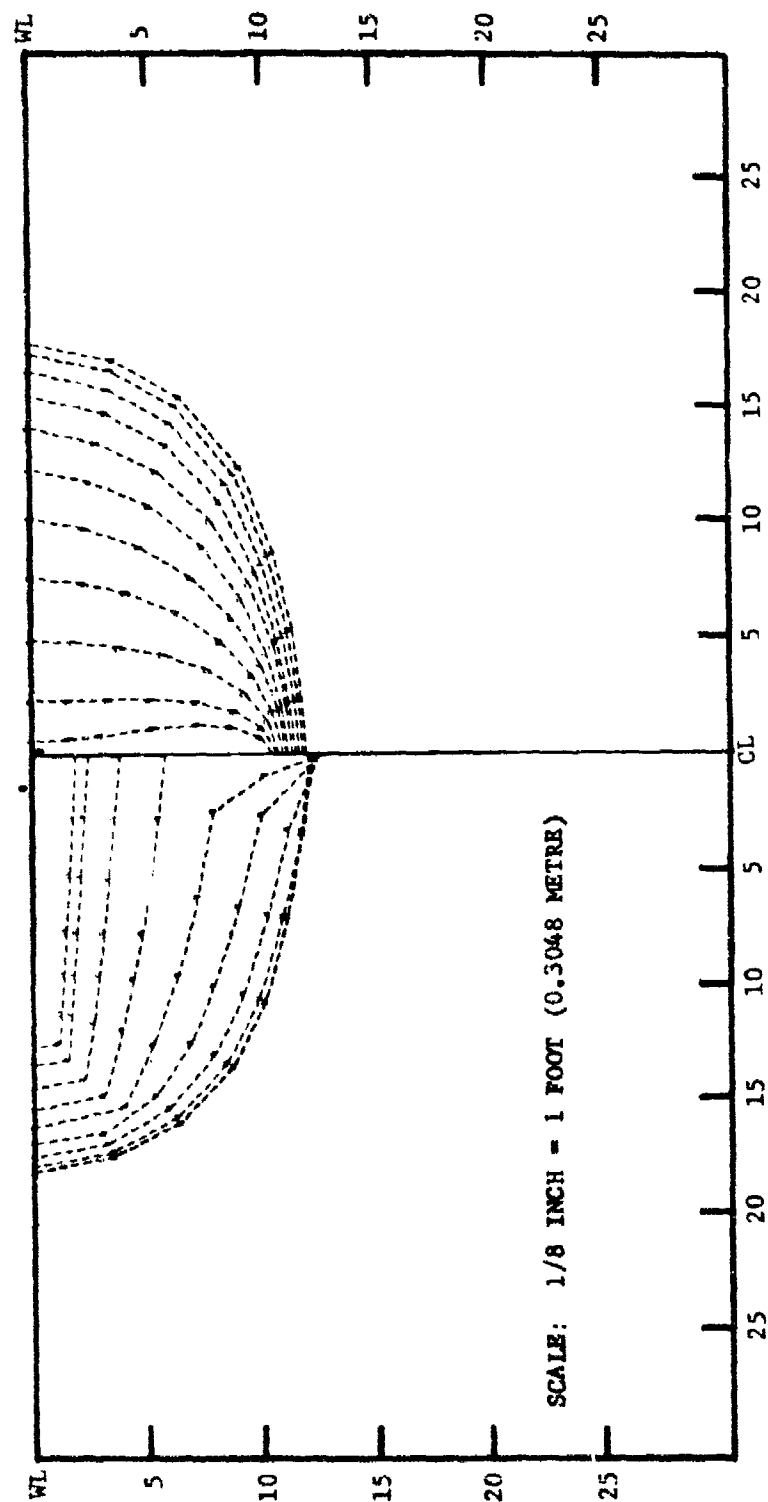SCALE: 1/8 INCH = 1 FOOT (0.3048 METRE)

Figure 4 – Computer-fit of FF 1006 Body Plan

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Figure 5 - Sketch of Ocean Construction Barge

Figure 6 – Zero Speed Measured and Predicted LCU 1610
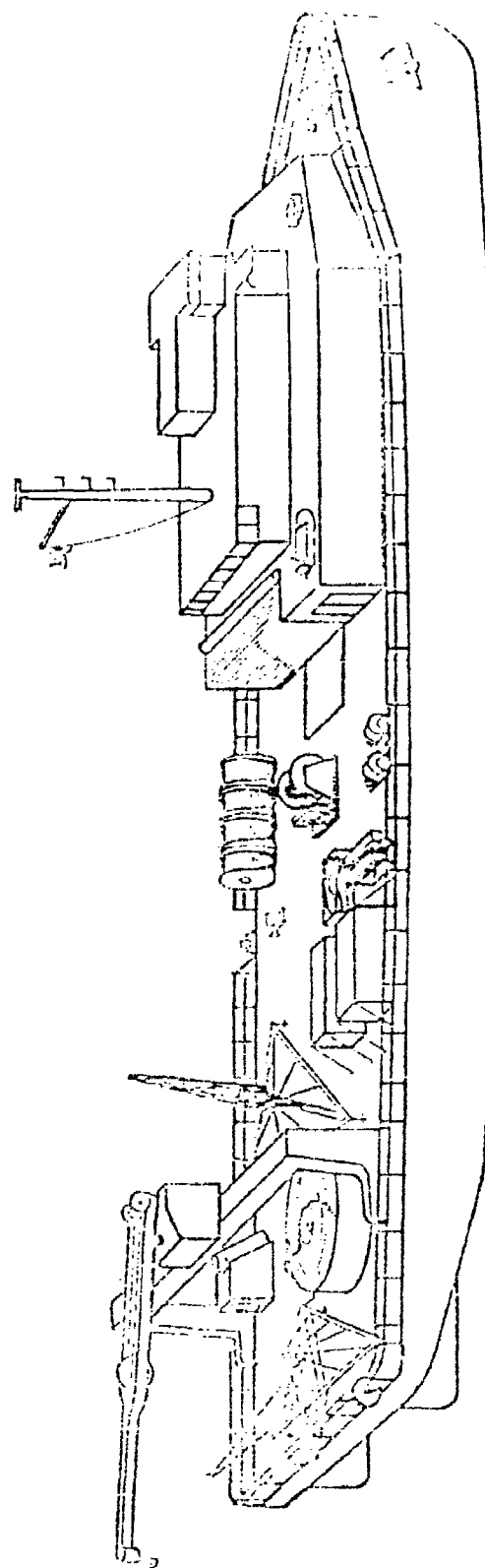Transfer Functions and Predicted Ocean
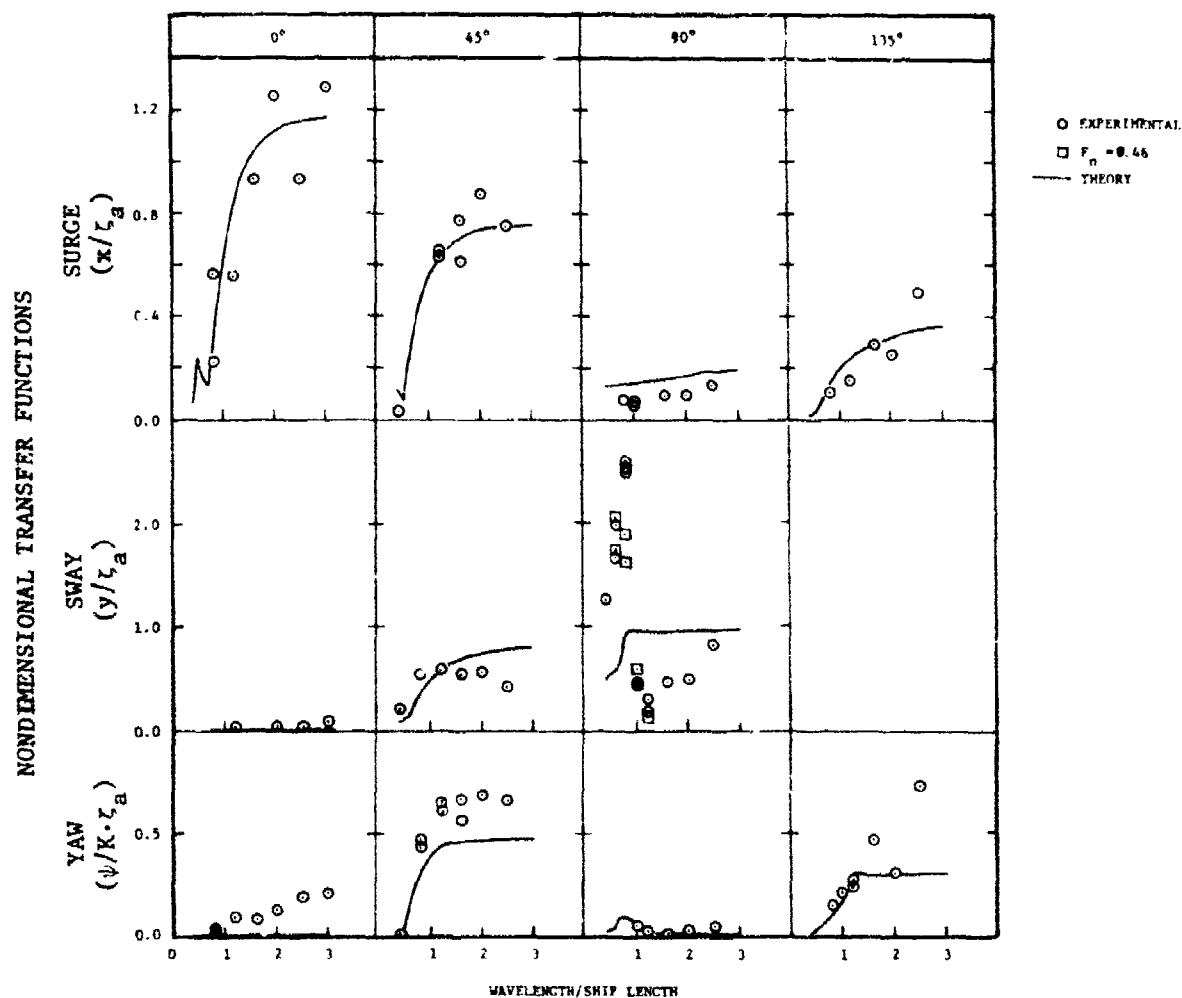Construction Barge Transfer Functions

Figure 7 – Nine Knot Measured and Predicted FF 1006
Transfer Functions (F_n = 0.15)

TABLE 1 - TABLE OF LCU 1610 SHIP PARTICULARS

	Model	Computer (Full-Scale)
Displacement, SW	1219 lb (553 kg)	344 l. tons (350 m. tons)
LBP	187.6 in (4.76 m)	134.0 ft (40.8 m)
Length at WL	168.8 in (4.29 m)	120.6 ft (36.8 m)
Beam	40.6 in (1.03 m)	29.0 ft (8.8 m)
Draft	6.7 in (0.17 m)	4.8 ft (1.5 m)
KG	N/A	8.9 ft (2.7 m)
GM	12.7 in (0.32 m)	9.1 ft (2.8 m)

TABLE 2 - TABLE OF OCEAN CONSTRUCTION BARGE SHIP PARTICULARS

	Computer (Full-Scale)
Displacement, SW	2349 l. tons (2387 m. tons)
LBP	260.0 ft (79.3 m)
Length at WL	247.0 ft (75.3 m)
Beam	48.0 ft (14.6 m)
Draft	7.9 ft (2.4 m)
KG	9.9 ft (3.0 m)
GM	19.5 ft (5.9 m)

TABLE 3 - TABLE OF FF 1006 SHIP PARTICULARS

	Model	Computer (Full-Scale)
Displacement, SW	859 lb (390 kg)	1929 l. tons (1960 m tons)
LBP	218.2 in (5.54 m)	308.0 ft (93.9 m)
Length at WL	218.2 in (5.54 m)	308.0 ft (93.9 m)
Beam	25.9 in (0.66 m)	35.9 ft (10.9 m)
Draft	8.6 in (0.22 m)	12.1 ft (3.7 m)
KG	N/A	13.4 ft (4.1 m)
GM	3.1 in (0.08 m)	4.3 ft (1.3 m)

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